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The ecological and economic aspects of a low emission limitation: a case study for Poland

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Abstract
Purpose The purpose of this study is to demonstrate ecological benefits of the thermal modernization of the central heating system in terms of the replacement of the central heating boiler for a modern boiler that is characterized by economically and ecologically beneficial parameters of the operation. It is particularly important in industrial regions where the concentration of harmful gases is high. An example is a region in Poland, which is the most industrialized and urbanized.
Methods The methodology is underpinned by life cycle thinking. The evaluation of the environmental benefits resulting from the modernization of heat sources was made with the use of life cycle assessment (LCA) technique, which was conducted according to the methodology defined in standards ISO 14040 and ISO 14044, using assessment methods included in Sima Pro 7 program with reference to a so-called representative building. The calculations were based on the assessment procedure of Ecoindicator 99, which allows for the presentation of the impact results with respect to 11 impact categories and/or three damage categories.
Results and discussion The LCA analysis of the considered heat sources points out unambiguously the most environmentally friendly option with a gas boiler combined with a solar collector. Nevertheless, this option belongs to one of the most expensive solutions of supplying thermal energy in the house. The optimum appears to be a variant using the ecological fuel for biomass, due to widely available biomass in the whole country, a low impact on the environment, the lowest operating costs and moderately high investment costs. The replacement of a low-efficient heat source in the municipal economy is the most energetically effective undertaking. It should be emphasized that the replacement of the inefficient boiler provides the greatest ecological effect in relation to investment costs.
Conclusions The aspect of the heat source selection is not only justified by economic and ecological reasons; it primarily results from the local availability of fuel. The use of the environmental technique—the assessment of the product life cycle—to support the decision of the heat source selection becomes a significant aspect in helping investors make environmentally friendly choices.

Keywords GHG savings · Ecology · Economy · Heat · LCA (life cycle assessment) · Poland

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1 Introduction

A large part of single-family houses in Poland is equipped with boilers with low energy efficiency. The boilers used to heat are mainly fired with solid fuels, which are in general of low quality. A separate, often practiced procedure especially in smaller towns is burning municipal waste in boilers, such as plastics, textiles, rubber, etc., which is not only forbidden, but also constitutes a threat to human health and life (Beccali et al. 2013). On 9 December 2009, the Ministry of the Environment in Poland published a letter from the Deputy Director of the Department of Waste Management on the ban on waste incineration in furnaces in households (Ministry of the Environment 2014).

The incineration of waste in domestic boilers is usually associated with generating a significant amount of dust and gas contamination, among others, CO, CO_2, SO_2, NO_x, PAHs (polycyclic aromatic hydrocarbons), dioxins, furans, as well as dusts and heavy metals.

Low emission is the pollution of the atmosphere, related primarily to generating thermal energy for the needs of individual households. Low emission is conventionally the emission from the chimneys of no more than 40 m. The authors of the manuscript use the term "low emission" due to the terminology adopted in Poland, where according to ERO (Energy Regulatory 2014) it is the emission *of air pollutants from the sources of low height above the ground, such as roads and intersections, landfills and home hearth, or municipal emission.* Unfortunately, the so-called low emission is not subject to any legal regulations; although the share of individual heating and small industrial and municipal boilers is estimated at the rate of 20–30 %, the aspect of the modernization of distributed individual heat sources becomes very important (Zastrzeżyńska and Gołębiowska 2012).

The problem of the air quality improvement, with a particular attention to minimizing the environmental impact of so-called low emission, is not the problem of only the lack of ecological and health-oriented education of the society, but first of all, the problem of a system as well as an economic nature. Some communes have begun to perceive and solve the system problem of low emission (Sadorsky 2014). In communes, numerous low emission reduction programs have appeared that aim primarily at ecological education, the statement of the needs and expectations of residents, as well as showing the sources for financing thermal modernization. Poland's first "low emission" restriction program took place in 1995 in Silesia. This program contributed to the intensive development of the research on the improvement of burning techniques and the construction of low-power coal-fired boilers.

Fig. 1 The location of Łaziska Górne commune

Table 1 The characteristics of heating sources and building

Source type		Boiler coal/gas/oil
Power of boiler—optimally	kW	20
Fuel used		Coal different product range/natural gas/oil/heat pump
Energy efficiency of primary source	%	70.82/94/92/420
Fuel parameters	MJ/kg, MJ/m^3, MJ/kg, kW	24.26/35.7/42.7
Energy performance of building		
Heat demand for central heating systems	GJ/year	121.8
Power demand for central heating systems	kW	12.6
Average area of a building	m^2	133

2 The scope of the environmental assessment

Modernization of the existing heating systems together with the thermal modernization of buildings will cause a substantial reduction of the emission of harmful substances into the air, and the use of devices based on renewable energy will allow for fuel savings, will burden less the environment and also will contribute to the increase of the commune attractiveness. Łaziska Górne commune, administratively assigned to Mikołów county, is located in the Upper Silesian Industrial District (Fig. 1). From an economic point of view, Łaziska Górne is a commune of an industrial and agricultural nature. A direct vicinity of large industrial plants, located in the commune and in its neighbourhood causes that the installations in the commune (including Tauron Production, branch of Łaziska Power, Coal Company S.A. KWK "Bolesław the Brave", Łaziska Steel Industry S.A., RE Alloys Ltd.) substantially affect the environment.

Łaziska Górne commune is located in the Upper Silesian province, which in 2009 introduced about 19 % of the national emissions of dust pollution, 19 % of gas pollution in total, 18 % of sulphur dioxide and carbon dioxide emission, 19 % of nitrogen oxides and 33 % of carbon monoxide. Taking into account that the surface of the Silesian province is less than 4 % of the total area of Poland, the region should be considered as one of the most polluted in the country (Główny Urząd Statystyczny 2014).

The consequence of the strong industrialization and urbanization of the area of Łaziska Górne commune is the considerable excess of emissions of harmful gases into the atmosphere. Moreover, there were significantly affected water relations, and surface water and groundwater were subject to pollution. The modernization of existing heating systems combined with thermal modernization of buildings will contribute to a significant reduction of emissions of harmful substances into the atmosphere. Table 1 shows the characteristics of heating sources and building in Łaziska Górne commune.

The most burdensome kind of emissions for residents is so-called low emission, which is not regulated legally in Poland.

"Low emission restriction program for Łaziska Górne Commune" indicates the actions that aim to reduce the pollution generated during the heating of single-family houses.

There are 22,467 people residing in Łaziska Górne commune (Główny Urząd Statystyczny 2014). The vast majority of energy (80 %) produced for heating purposes in the commune of Łaziska Górne is produced in coal-fired boilers (Fig. 2). The residents of this community, in addition to coal with a large product range, use coal dust and coke. This situation adversely affects the air quality in the community especially during the heating season (Zastrzeżyńska and Gołębiowska 2012). Nationally, single-family houses are also the most heated with coal (nearly 70 %), but this is a part slightly lower than in the case of Łaziska Górne commune (Energy Regulatory 2014).

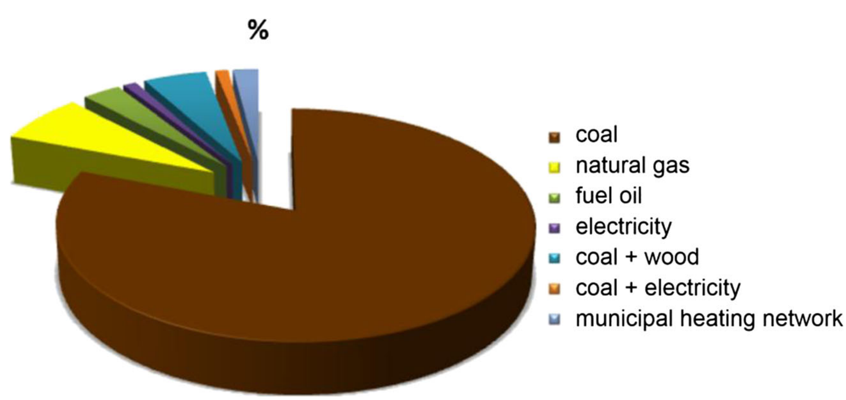

Fig. 2 The structure of fuels used for heating of single-family houses in the commune Łaziska Górne (Zastrzeżyńska and Gołębiowska 2012)

Table 2 The operating parameters and emission analysed heat sources

Type of the heat source	Coal boiler	Coal boiler with feeder	Gas boiler	Oil boiler	Heat pump	Biomass boiler	Coal boiler with feeder and solar collector
1. The fuel	Coal different assortment	Coal peas	Natural gas	Fuel oil	Electricity	Biomass	Coal peas
2. The energy efficiency of the heat source (%)	70	82	94	92	420	85	82
3. The parameters of fuel (MJ/kg)	24	26	42.8	42.8		12	26
4. Fuel consumption	7.3 (Mg/year)	5.7 (Mg/year)	3629.5 (m^3/year)	3708.4 (kg/year)	8033.0 (kWh/year)	11.9 (Mg/year)	5.4 (Mg/year)
5. Cost of fuel (euro)	956	882	1469	4150	861	708	836
6. Total cost of operation (euro)	995	913	1505	4150	861	772	865
7. Save/increase in operating costs [euro/year]	–	−82	−510	−3155	134	223	130
8. The total emission of pollutants (kg/year)	604	423	1.03	131.08	0	131.08	399
9. CO_2 emissions (kg/year)	14,600	11,400	7128	7098	0	0	10,800
10. CO emissions (kg/year)	329	257	0.98	3	0	78.72	243
11. SO_2 emissions (kg/year)	93	46	0.01	82	0	2.38	43
12. NO_X emissions (kg/year)	7	6	0.00	22	0	8.33	5
13. Emissions of dust (kg/year)	175	114	0.04	8	0	41.65	108
14. Ecological effect in relation to the building representative:							
Reduction of emissions of pollutants (kg/year)	X	181	603	489	604	473	231
Reduce carbon dioxide emissions (kg/year)	X	3200	7472	7502	14,600	14,600	3800
15. LCA value of the environmental impact of heat sources (Pt/year)	573	370	29.2	192	456	112	348

Table 3 Scenario no. 1 (optimal): the structure of the share of fuel and energy in the production of thermal energy in single-family houses in Łaziska Górne commune

Structure of fuel and energy consumption	2012	2015	2020	2025
Solid fuels (coal, coke)	80.40 %	75.70 %	70.40 %	65.00 %
Gaseous fuels	17.20 %	19.00 %	21.00 %	22.30 %
Fuel oil	1.70 %	1.80 %	1.90 %	1.90 %
Biomass	0.70 %	1.50 %	2.70 %	3.80 %
Heat pump	0 %	2 %	4 %	7 %

According to the census carried out in Poland in 2011, there were 5.5 million single-family residential buildings. It should be emphasized that the number of single-family houses in 10 years increased by 15.2 %, while the multi-housing only by 4.0 % (The results of the National Census of Population and Housing 2011). It can be assumed that the number of single-family houses in Poland will continue to grow.

Life cycle assessment (LCA) is a technique to evaluate environmental impacts, which creates possibilities for their identification, prioritization, and also allows consumers to make ecologically determined choices with a minimum impact on the environment (Zarębska and Dzikuć 2013). LCA technique has been described by the International Committee for Standardization in the standards of the ISO 14040: PN-EN ISO 14040:2009 and PN-EN ISO 14044:2009 (ISO 14040 2006; ISO 14044 2006). LCA is a technique for assessing various aspects associated with development of a product and its potential impact throughout a product's life from raw material acquisition, processing, manufacturing, use and finally its disposal (Varun and Prakash 2009; Malca et al. 2014; Dzikuć and Urban 2014). Nowadays in Europe, LCA analysis is a recognized and recommended tool for the assessment of environmentally friendly projects in many areas of the economic activity, including the construction sector (Björklund 2012; Dąbrowski and Dzikuć 2012).

The evaluation of the environmental benefits resulting from the modernization of heat sources was made with the use of LCA technique, which was conducted according to the methodology defined in previously mentioned standards ISO 14040 and ISO 14044, using assessment methods included in Sima Pro 7 program with reference to a so-called representative building (Dzikuć 2013b; Dzikuć and Dzikuć 2013).

The key issue in the LCA analysis remains the quality and representativeness of the inventory data that determines the uncertainty of final results. The selection of the final categories of LCIA has been developed on the basis of the significant impact of emissions from boilers of various types on human health and ecosystem quality. The data on the LCI environmental impact analysis refers to the literature data (Zastrzeżyńska and Gołębiowska 2012). Due to the lack of information about the selected research method of pollution emissions from boilers and the error of the measuring device, it is not possible to determine precisely the quantitative data quality.

The parameters of the representative building were determined based on the averaged values of construction and technical data from the survey carried out for the publication titled "Low emission restriction program for Łaziska Górne Commune". According to the averaged survey data, the heated surface of the representative building is 133 m^2, the heated volume is 586 m^3 and the average heat transfer coefficient for the opaque external walls of the building is 0.99 W/m^2*K. The most common types of boilers in the central heating system were solid fuel, gas and oil boilers, respectively, with the maximum efficiency of 70.82/94/92 %, with the heat output of 20 kW. The demand for thermal energy for the central heating is 121.8 GJ/year, and the demand for thermal

Table 4 LCA analysis results for the optimal scenario

Structure of fuel and energy consumption	LCA analysis result for the year 2012 (Pt/year)	LCA analysis result for the year 2015 (Pt/year)	LCA analysis result for the year 2020 (Pt/year)	LCA analysis result for the year 2025 (Pt/year)
Solid fuels (coal, coke)	2,303,460	2,168,805	2,016,960	1,862,250
Gaseous fuels	25,112	27,740	30,660	32,558
Fuel oil	16,320	17,280	18,240	18,240
Biomass	3920	8400	15,120	21,280
Heat pump	0	11,200	22,400	39,200
The total environmental impact of heating of family houses	2,348,812	2,233,425	2,103,380	1,973,528

Table 5 Scenario no. 2 (preference gaseous fuel): the structure of the share of fuel and energy in the production of thermal energy in single-family houses in Łaziska Górne commune

Structure of fuel and energy consumption	2012	2015	2020	2025
Solid fuels (coal, coke)	80.40 %	76.40 %	72.00 %	66.60 %
Gaseous fuels	17.20 %	20.00 %	23.00 %	27.00 %
Fuel oil	1.70 %	1.70 %	1.80 %	1.90 %
Biomass	0.70 %	0.90 %	1.20 %	1.50 %
Heat pump	0 %	1 %	2 %	3 %

energy for hot water is 14 GJ/year, total power requirement is 15.5 kW.

The aim of the LCA analysis is to demonstrate ecological benefits of the thermal modernization of the central heating system in terms of the replacement of the central heating boiler for a modern boiler that is characterized by economically and ecologically beneficial parameters of the operation.

The analysis includes the environmental impact taking place in a detached building. The acquisition of fuel was not analysed, with the exception of the heat pump which consumes electricity. The system boundaries for the analysed heat sources includes generating a particular unit of thermal energy (fuel consumption and material and energy emissions) without the environmental impact of the production of boilers and the later stage of recycling. The environmental impact related to the production, construction and arrangement of the infrastructure necessary to transport and/or store fuel was omitted as well. The functional unit is the demand for thermal energy in kilowatt hours of the representative building throughout a year.

The calculations were based on the assessment procedure of Ecoindicator 99, which allows for the presentation of the impact results with respect to 11 impact categories and/or three damage categories.

3 The results of the environmental assessment with LCA

Evaluating the data and results of the analysis (Table 2), it is possible to conclude that the parameters of the coal boiler, which is recommended for modernization, are the worst among the analysed examples except the aspect related to the cost of fuel, and the total costs of the operation at the same time and to the fact that this solution is characterized by the lowest costs of the boiler purchase (about 600 euros). The highest total cost of the operation is attributed to the oil boiler (about 4150 euros) and gas boiler (1470 euros); hence, the values in verse 8 of the Table 2 respectively to the heat source are negative. The highest operational savings are generated by biomass boilers (223 euros) that are less popular among the users of single-family houses. Another installation that provides savings associated with the operation is the heat pump, which provides savings of 134 euros and a retort coal boiler with a feeder and with a solar collector (130 euros). It is necessary to point out that in order to determine fuel costs, the averaged value of the price was assumed and the fact that the price of a new boiler installation was not included in the calculation. It is the result of the fact that there are substantial differences in the prices of particular installations. Thus, except the low current expenditure related to the use of e.g. the heat pump, it is necessary to take into consideration the costs connected with the purchase of the heating system. Table 2 shows, after the "Low emission reduction program for Łaziska Górne Commune", that the production of thermal energy from biomass-fired boiler does not generate CO_2 emission into the atmosphere. It is true only when the balance of this gas is included in the final effect of the growth of the plant that produces a pellet (Stolarski et al. 2013; Glembin et al. 2012). The balance assumes that this amount of CO_2 gas, which is absorbed from the atmosphere at the time of the plant growth

Table 6 LCA analysis results for scenario preferred gaseous fuels

Structure of fuel and energy consumption	LCA analysis result for the year 2012 (Pt/year)	LCA analysis result for the year 2015 (Pt/year)	LCA analysis result for the year 2020 (Pt/year)	LCA analysis result for the year 2025 (Pt/year)
Solid fuels (coal, coke)	2,303,460	2,188,860	2,062,800	1,908,090
Gaseous fuels	25,112	29,200	33,580	39,420
Fuel oil	16,320	16,320	17,280	18,240
Biomass	3920	5040	6720	8400
Heat pump	0	5600	11,200	16,800
The total environmental impact of heating of family houses	2,348,812	2,245,020	2,131,580	1,990,950

Table 7 Scenario no. 3 (stagnation): the structure of the share of fuel and energy in the production of thermal energy in single-family houses in Łaziska Górne commune

Structure of fuel and energy consumption	2012	2015	2020	2025
Solid fuels (coal, coke)	80.40 %	79.00 %	77.00 %	76 %
Gaseous fuels	17.20 %	18.60 %	20.60 %	21.60 %
Fuel oil	1.70 %	1.60 %	1.70 %	1.60 %
Biomass	0.70 %	0.80 %	0.70 %	0.80 %
Heat pump	0 %	0 %	0 %	0 %

(photosynthesis) will be emitted to it when the fuel is burnt with the use of energy.

A lack of the emission into the atmosphere was shown in the analysis of the heat pump as one of the analysed options. The value of the environmental impact is not included in the size of "low emission" electricity used to generate heat in the heat pump is produced in power plants (elsewhere), so emissions are included in the emissions of the industrial power. It is necessary to notice that it is due to the fact that electric energy consumed to generate heat is not produced on site and it is not defined as so-called low emission. A discharge of the emission into the atmosphere takes place in the surrounding of the place of electric energy generation that is in the power plant, which was included in LCA analysis. A high value of LCA analysis (456 Pt) of this case is associated with the production of electric energy from the combustion of solid fuel and with the losses occurring during the transmission of electric energy to the recipient. It is one of the most expensive solutions for the investor when it comes to the purchase of the installation for producing thermal energy (about 4760 euros).

Table 2 presents the operating and emission parameters of eight analysed heat sources along with the results of the life cycle assessment. A "grey" column (no. 2) corresponds to the example that is most commonly met in old individual heat sources in Łaziska Górne.

High costs of the purchase, except for the most expensive heat pump, are characteristic for two next solutions among the analysed options, that is a gas and coal boiler with the use of a solar collector to generate thermal energy. It is an appropriate environmentally friendly solution; however, a low interest of the users in solar collectors is mainly due to the high price of purchase (Glembin et al. 2012).

The replacement of a low-efficient heat source in the municipal economy is the most energetically effective undertaking. It should be emphasized that the replacement of the inefficient boiler provides the greatest ecological effect in relation to investment costs. The use of a more efficient device causes the reduction of the consumption of energy resources (Dzikuć 2013a; Wanga et al. 2011). Moreover, this reduction can compensate for the increase of heating costs associated with the replacement of the resource energetically cheaper (coal) used to heat buildings for a more expensive energy carrier (natural gas). The most significant criteria of a boiler selection are the criterion of the energetic efficiency and the ecological criterion.

As part of the quantitative analysis of the uncertainty associated with the forecasts of using fuels for heating single-family houses, scenario analysis tools were used—in addition to a stagnant scenario, an optimal scenario and the use of gas preference scenario were constructed.

Scenario 1—an optimal scenario (of sustainable development of the energy sector with a preference for thermal modernization actions). The scenario includes the elimination of exploited and not complying with the emission limits, individual heat sources with the optimal use of energy and using renewable energy sources (Table 3).

Assuming that all buildings in the commune (approximately 5000) have a comparable surface to the reference building (the reference building is the averaged surface of

Table 8 LCA analysis results for scenario stagnant

Structure of fuel and energy consumption	LCA analysis result for the year 2012 (Pt/year)	LCA analysis result for the year 2015 (Pt/year)	LCA analysis result for the year 2020 (Pt/year)	LCA analysis result for the year 2025 (Pt/year)
Solid fuels (coal, coke)	2,303,460	2,263,350	2,206,050	2,177,400
Gaseous fuels	25,112	27,156	30,076	31,536
Fuel oil	16,320	15,360	16,320	15,360
Biomass	3920	4480	3920	4480
Heat pump	0	0	0	0
The total environmental impact of heating of family houses	2,348,812	2,310,346	2,256,366	2,228,776

the other buildings), the following tables determine the environmental impact of the assumed three scenarios with regard to LCA analysis.

The total (annual) environmental impact of single-family houses in the considered commune, over the years, for the optimal variant, is definitely reduced. The difference between extreme years is the highest and amounts to 375,284 Pt (Table 4).

Scenario 2—a scenario with limited thermal modernization and preference of gaseous fuels. The scenario assumes a gradual modernization of local and individual heat sources with a preference for gaseous fuels. A moderate growth of renewable energy sources (Table 5).

The total (annual) environmental impact of single-family houses in the considered commune, for the variant preferring gaseous fuels, is significantly reduced. The difference between extreme years is 257,862 Pt (Table 6).

Scenario 3—a stagnation scenario, primarily consists of an omission of thermal modernization works. The scenario assumes the preservation of the current structure of heat supply. The performance of the minimum modernization actions on heat sources without the implementation of renewable energy sources and the development of the gas system (Table 7).

The total (annual) environmental impact of single-family houses in the considered commune, for the stagnation variant, is slightly decreased. The difference between extreme years is 120,036 Pt (Table 8).

If assumed that the commune implements scenario no. 1 optimal, about 255,248 Pt less air pollutants would go to the environment, in comparison to scenario no. 3 stagnant (Tables 4 and 8).

In the analysed commune, the average time of using central heating boiler is about 18 years. From a technical, economic and ecological point of view, the duration of use of the boiler should be no longer than 10 years.

The above analysis covers a period of 1 year due to two aspects. The first is the variability of the number of buildings in time and the (the second aspect) thermal modernization of the existing building substance. The time interval of 1 year is also a universal interval; it is possible to make calculations in different time configurations. The studied period of time also allows for the expansion of the considered scale, for example to the area of the country or region, of course, taking the appropriate number of buildings into account.

4 Concluding remarks and discussion

The aspect of the heat source selection is not only justified by economic and ecological reasons; it primarily results from the local availability of fuel. If the urban infrastructure does not provide the supply of the natural gas from the network, this type of a thermal energy source is not considered. It is also significant to have the availability on the local market of other types of fuels, the choice of which, by virtue of big transportation distances, could eventually affect the increase of the costs of using heat sources (e.g. coal, oil, etc.).

A significant complication associated with the choice of a more environmentally friendly fuel for heating family houses is the low income of a large part of the society in Poland. Households, in order to reduce housing costs, often use the cheapest fuel, which is coal. Furthermore, the coal is often of a poor quality, because in Poland, there are not norms related to the quality of fuels used in single-family houses. It is difficult to compare the conditions in Poland to the countries of so-called old European Union (EU-15), because nowadays, Poland is facing the solution of problems that in most European Union countries have not existed for several decades (Adamczyk and Dzikuć 2014). Moreover, in particular EU countries, a decisive element for the level of demand for energy to heat buildings are climate conditions.

The LCA analysis of the considered heat sources points out unambiguously the most environmentally friendly option with a gas boiler combined with a solar collector. It is necessary to emphasize, however, that the LCA analysis did not include in the environment impact the ecological costs of the production of gas fittings and pipelines, their arrangement and potential emissions into the atmosphere due to the leaks of the installation. Nevertheless, this option belongs to one of the most expensive solutions of supplying thermal energy in the house.

The optimum appears to be a variant using the ecological fuel for biomass, due to widely available biomass in the whole country, a low impact on the environment, the lowest operating costs and moderately high investment costs.

The use of the environmental technique—the assessment of the product life cycle—to support the decision of the heat source selection becomes a significant aspect in helping investors make environmentally friendly choices.

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